IDWR/UI ESPA GROUND WATER FLOW MODEL

This is a brief description of the IDWR/UI ground water flow model and its adaptation to the ESPA. A general outline description of the model is contained in Appendix B. A detailed description of the model is provided by Johnson and Brockway, 1983.

PROGRAMS

The IDWR/UI ground water flow model consists of two separate programs. The first is a recharge program which summarizes and processes input data for each component of the aquifer water balance and generates a combined recharge or discharge (net recharge) source term for each grid cell for each timestep. Water balance elements are precipitation, crop consumptive use, deep percolation from surface irrigation, tributary valley underflow and surface flow, point source pumping and injection wells, and streambed gains and losses.

A second program simulates aquifer response to net recharge, given estimates of geohydrologic parameters. The model simulates two-dimensional flow. Head values are calculated by an **iterative** solution of finite difference ground water flow equations (Johnson and Brockway, 1983). The model computes change in aquifer storage resulting from changes in ground water surface elevation and also computes reach inflow and outflow between surface streams and the aquifer. The simulation program contains a calibration routine which allows either automatic or manual adjustment of parameters in order to match water table head values, gradients, and spring discharge at reference timesteps.

MODEL BOUNDARIES

The IDWR/UI ground water flow model was adapted to the ESPA by establishing boundaries around the ESPA area previously defined by the USGS shown in Figure 4. Model boundaries do not exactly correspond to USGS ESPA boundaries for reasons of hydrologic interpretation. The encompassed area (Figure 5) was overlain with a 5 km grid and the model boundary was characterized as either fixed head (hydraulically connected to the river) or fixed flow (no flow or constant flow). Hydraulically connected fixed head cells (aquifer discharge/recharge areas) were chosen along the southern boundary of the Snake River from above American Falls Reservoir to Minidoka Reservoir and from Kimberly to King Hill. These two reaches represent the major spring discharge areas from the ESPA. All other boundaries are specified as either no flow or, where tributary valley underflow occurs, fixed flow.

Figure 4. Eastern Snake Plain Aquifer and Model Boundary

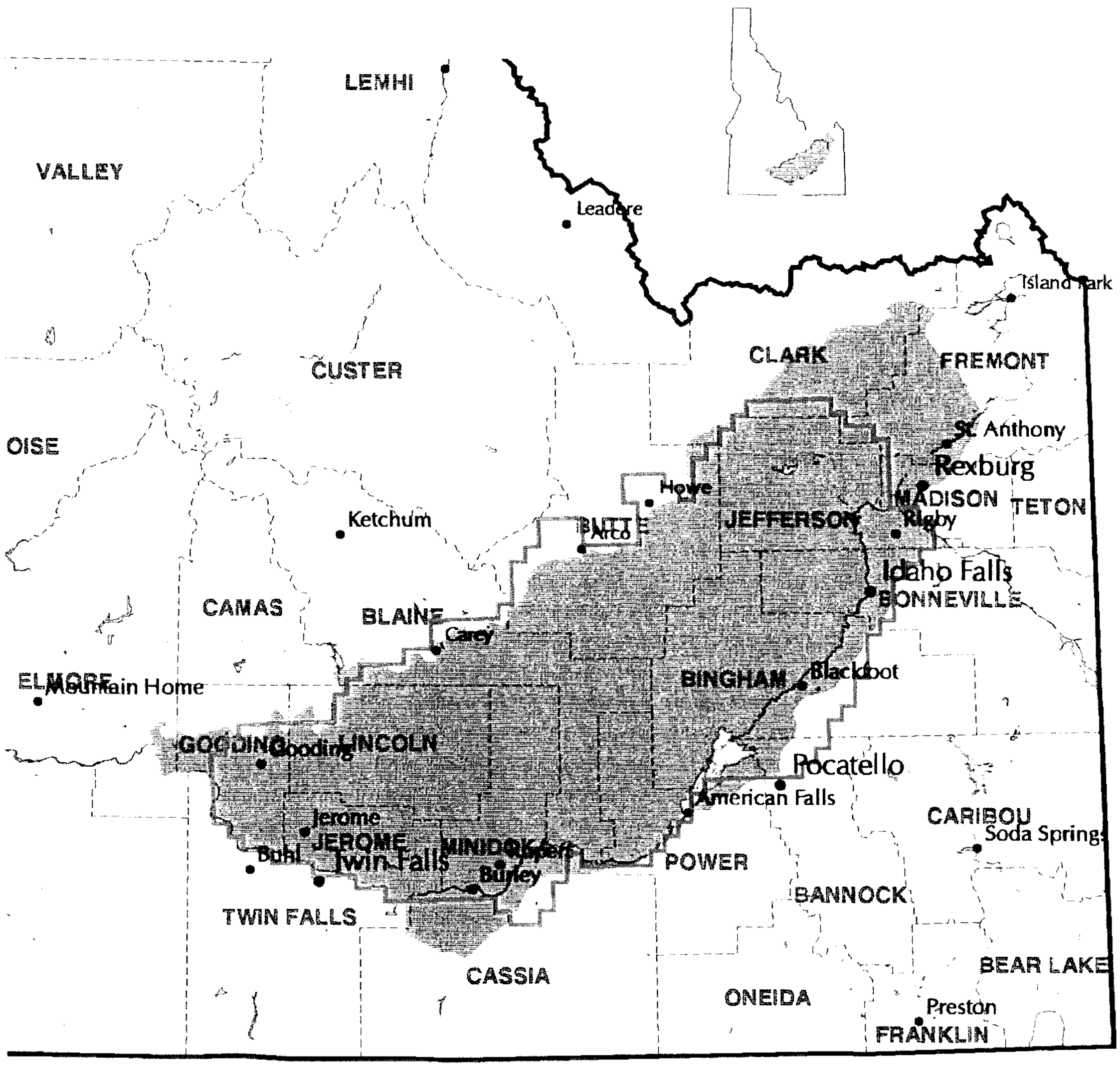
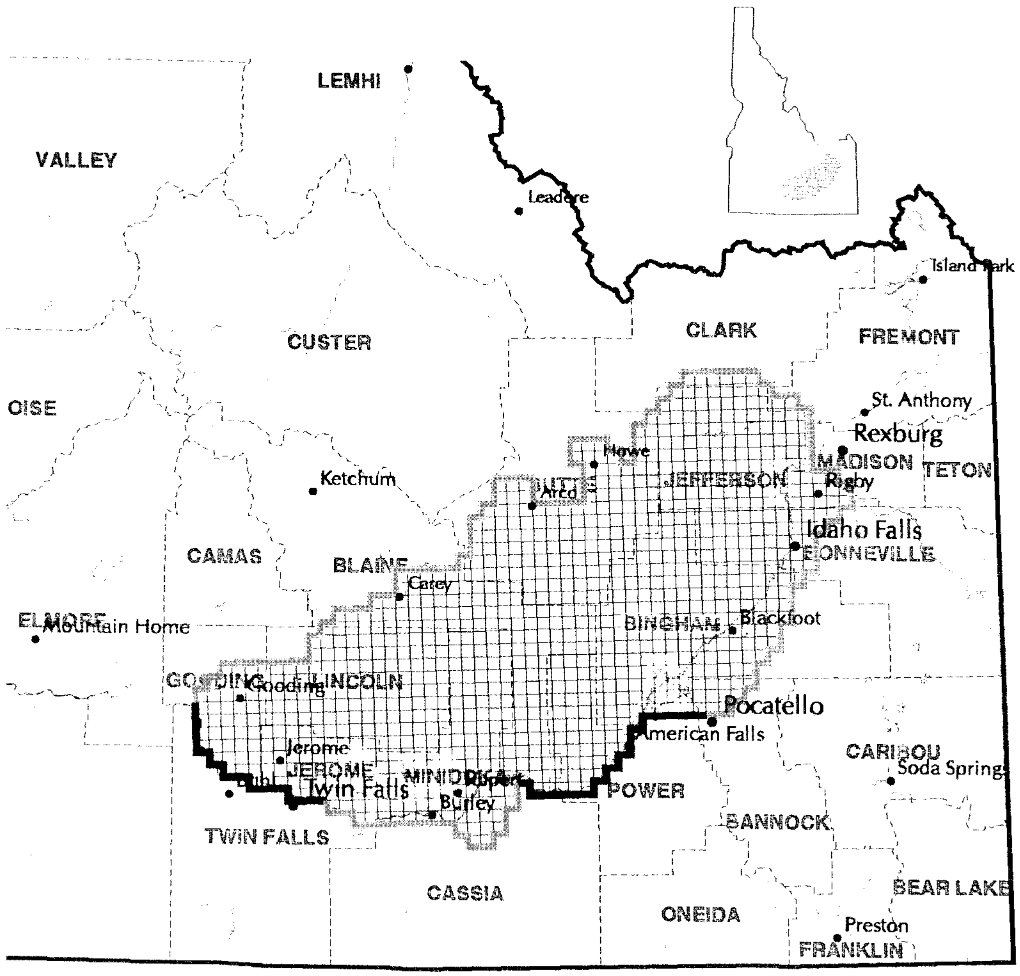


Figure 5. Eastern Snake Plain Aquifer Model



□ 5K Model Cell Size (Hydraulically Connected) (No Flow)

ESPA MODEL CALIBRATION

Application of the IDWR/UI ground water flow model as a management tool for the Upper Snake River basin is preceded by calibration of the model to the ESPA. The purpose of the calibration is to adjust model parameters to provide the best possible match of simulated and measured values of water table elevation and spring discharge. Previous calibrations of the model to the ESPA are described by de Sonneville (1974) and Johnson, et al (1985). The ESPA model was recalibrated for this study to more accurately simulate spring discharge. Ground water level measurement data taken for the USGS RASA studies (Garabedian, 1992) for the years 1980-81 were the most extensive and comprehensive available and were selected for model calibration.

PARAMETERS

The calibration parameters for the ESPA model are transmissivity and storage coefficient. The program compares simulated water table gradients to reference gradients and adjusts transmissivity values based on the difference. Storage coefficients are adjusted based on differences between simulated head values and reference head values. Final deviations of simulated head values from reference head values as well as deviations of simulated spring discharges at hydraulically connected cells from historic spring flows are used to evaluate the calibration.

NET RECHARGE

A combined recharge source term was generated by the recharge program for calibration using 24 half month timesteps from April 1980 through March 1981. The source term represents net recharge and is the calculated recharge or discharge to the aquifer at each grid cell for each timestep.

Year 1980 irrigated acres by water source, ground or surface water, were used to develop the net recharge due to irrigation practices for each model cell (see Appendix C). Ground water withdrawals for irrigation were set equal to the net evapotranspiration rate (see following paragraph) multiplied by the number of ground water irrigated acres in each cell. Surface water irrigated acres for each grid cell were assigned when possible to an irrigation entity (named surface water acres) associated with a specific diversion point on the river. Surface water irrigation recharge from each entity over its service area was calculated as the total diversion minus net evapotranspiration volume minus return flow. Net evapotranspiration was calculated as net evapotranspiration rate (see following paragraph) times service area acres. The recharge for surface water acres not assigned to a specific entity (unnamed surface water acres) was based on the average recharge of the named surface water irrigated acres in the surrounding cells. Surface irrigation diversions to a service area were taken from measurements reported by the Water District 1 watermaster annual report (Water District 1, 1980, 1981). Return flows were obtained from measurements taken for the USGS RASA study and estimated from miscellaneous measurements.

To compute net evapotranspiration rates, climatological data for 1980-81 was input for 11 climatic regions for each timestep based on the locations of representative weather stations. These data consist of total precipitation, average daily solar radiation, average mean daily temperature, average daytime wind speed, and average daily minimum relative humidity. Total evapotranspiration was computed for each crop type using a method developed by the University of Idaho (Allen and Brockway, 1983) with 1980-81 climatological data as input. An average evapotranspiration rate for all nodes in each climatic region was calculated based on the 1980 crop type distribution as reported by local Farm Service Agency offices. Net evapotranspiration was computed by subtracting effective precipitation from the average evapotranspiration.

Recharge from precipitation on non-irrigated areas was calculated for each climatic region as a portion of measured precipitation based on assumed effectiveness in reaching the aquifer. A part of the measured precipitation either evaporates or is used by native vegetation. Effectiveness coefficients were chosen based on predominate types of land cover in each climatic region and applied to the actual 1980-81 precipitation.

Tributary valley underflow and direct surface runoff estimates were made using previous aquifer studies and were input to the model at appropriate boundary locations. Underflow and surface runoff estimates (Table 1) total 1,605,300 acre-feet from 14 tributaries.

Several streams and canals overlying the ESPA are not hydraulically connected to the aquifer. Surface reach gains (losses) were calculated as outflow minus inflow plus diversions minus return flows plus reservoir storage change plus reservoir evaporation. Actual 1980-81 measurements were used except for return flows, which were estimated. Computed reach recharge was distributed to nodes underlying surface sources having significant values (Table 2).

Table 1. ESPA Model Tributary Basin Annual Recharge
(acre-feet per year)

Name	Underflow	Surface Flow	Total Basin Input
Big Wood	0	22,000	22,000
Silver Creek	38,000	0	38,000
Little Wood	24,000	31,000	55,000
Big Lost	114,000	51,000	165,000
Little Lost	100,000	47,000	147,000
Birch Creek	70,000	0	70,000
Blackfoot	25,000	0	25,000
Raft River	63,000	0	63,000
Portneuf	22,600	0	22,600
Medicine Lodge and Deep Creek	15,700	0	15,700
Beaver Creek	59,200	17,000	76,000
Camas and Big Bend	266,700	26,400	293,100
Warm Springs	24,700	0	24,700
Henrys Fork	588,000	0	588,000
Total	1,410,900	194,400	1,605,300

Table 2. Recharge to ESPA from Streams and Canals
May 1980 through April 1981
(acre-feet)

Snake River, Shelley to Blackfoot	111,400
Snake River, at Blackfoot to near Blackfoot	140,000
Snake River, Minidoka to Milner	281,400
Snake River, Milner to Kimberly	-23,000
Camas Creek, 18 mile to Camas	21,500
Camas Creek, Camas to Mud Lake	4,900
Mud Lake	16,400
Beaver Creek, Dubois to Camas	17,400
Little Lost River	47,700
Big Lost River	51,500
Milner Gooding Canal	146,200
Little Wood River, above Picabo to Richfield	10,600
Little Wood River Richfield to above Milder Gooding Canal	26,900
Little Wood River, above Milder Gooding Canal to near Gooding	5,900
Big Wood River, Magic Reservoir to Shoshone Canal	52,700
Big Wood River, above Thorn Creek to Gooding	-20,900
Big Wood River, Gooding to near Gooding	7,900
Total	1,066,500

The eastern portion of the ESPA is overlain by the Henrys Fork-Rigby Fan perched alluvial aquifer (HFA) which redistributes recharge within that system, eventually interacting with the deeper ESPA through leakage. A ground water flow model of the HFA (Johnson, Brockway, and Luttrell, 1985) was used to determine the recharge due to leakage to the ESPA model. A total of 766,587 acre-feet was added to nodes in the ESPA model which underlie nodes in the HFA model. A discussion of the HFA model and interaction with the ESPA model is given in Appendix D.

PROCEDURE

The calibration period was from April 1980 through March 1981 using half month timesteps. The initial values of transmissivity and storage coefficients were taken from the previous calibration based on 1966 data (Newton, 1978). The depth to water data collected by the USGS during the 1980 mass measurements (spring and fall, 1980) for the RASA study (Garabedian, 1992) were used to generate reference water tables. Spring 1981 water table elevations were developed by adjusting the spring 1980 water table based on observation well data for the spring of 1981. This provided three sets of reference head values over the ESPA on which to base the calibration.

The three sets of reference head values (spring and fall 1980, and spring 1981) and the magnitude and location of the aquifer spring outflows (reach gains) were considered more accurate than the other components of the water balance. The goal of calibration was to adjust transmissivity and storage coefficients to best match reference heads and reproduce historic aquifer discharges.

Model calibration required multiple trial simulations. Each trial simulation repeated the annual cycle of 24 timesteps until a steady state condition was reached. During the initial calibration run the transmissivity and storage coefficients were alternately adjusted based on the fit for the final timestep, number 24 (spring 1981). Using the new values, transmissivity and storage coefficients were then adjusted to begin the next annual cycle based on the closeness of fit at timestep number 11 (fall 1980). Deviations of computed head values from reference head values were insensitive to the adjustment of the storage coefficients after an initial improvement. Calibration continued by adjusting transmissivity alternately on timestep numbers 11 and 24 until there was no significant reduction in the total head value deviations from reference for both timesteps. Adjustments in the transmissivity values for specific cells were then made manually to more closely match historical spring discharges. Calibration continued until the simulated aquifer discharge and the head value deviations from reference values were considered insignificant.

The mean head value error over the entire ESPA for calibration timesteps 11 and 24 were 3.6 and 3.8 feet, respectively. These values are small when considering that the depth of the ESPA in many locations is in excess of one thousand feet. The computed outflows in the most significant aquifer discharge reaches, Shelley to Neeley and Kimberly to King Hill, were 1.93 and 4.13 million acre-feet per year, respectively. This was close to the historic outflows of 1.90 and 4.34 million acre-feet per year, respectively (Garabedian, 1992). The total change in storage calculated for the calibration period was 24.5 thousand acre feet. For comparison, the total estimated ESPA storage in the top 200 feet is 80 to 120 million acre-feet (Lindholm, 1993). Calibration resulted in the final transmissivity and storage coefficient data sets to be used in all subsequent model simulations.

ESPA BASE STUDY

A base study was run to establish a reference for estimating the magnitude of the change caused by each "what if" simulation. The ESPA base study is defined in this report as the model simulation of aquifer discharges and water table elevations which would result at equilibrium from a continuation of current average aquifer inputs and withdrawals. The following is a description of the development and use of the base study.

NET RECHARGE

A combined recharge source term was generated by the recharge program for the base study using 24 half month timesteps representing the long term average net recharge to the aquifer under present level of development and pattern of use at each grid cell for each timestep. The "present" in this report is data and information from 1992 or, in some cases, an average of a period of years preceding 1992, such as 1982 through 1992, during which conditions remained stable.

Year 1992 irrigated acres by water source, ground or surface water, were used to develop the net recharge due to irrigation practices for each model cell (Appendix C). The total 1992 irrigated acreage included in the modeled area was 1,428,961, of which 817,874 acres were irrigated with ground water. Recharge on the irrigated and non-irrigated acres was determined in the same fashion as used for the calibration (see "ESPA Model Calibration" section), except that surface irrigation diversions to a service area were determined by averaging the 1982 through 1992 measurements reported in the Water District 1 watermaster annual report (Water District 1, 1982-1992).

Net evapotranspiration in each of the 11 climatic regions for the base study was calculated using the same procedure used for the calibration except that long term averages (1951 through 1980) of climatological data were used. Crop distribution for the base study was assumed identical to that used in calibration.

Recharge from precipitation on non-irrigated areas was calculated as in the calibration except that long term averages (1951 through 1980) were used for precipitation. The tributary valley underflow estimates (Table 1) used for the calibration were also used in the base study. The stream and canal reach gains (or losses) were determined as described for the calibration except that an average of 1982 through 1992 historical gains were used. Base condition net recharge from streams and canals equaled 733,400 acre-feet (Table 3). Leakage values between the HFA and ESPA computed by the HFA model for calibration were also used in the base study.

Table 3. Base Study Recharge to ESPA from Streams and Canals
(acre-feet)

Snake River, Shelley to Blackfoot	217,300
Snake River, at Blackfoot to nr Blackfoot	97,300
Snake River, Minidoka to Milner	93,300
Snake River, Milner to Kimberly	-86,4000
Camas Creek, 18 mile to Camas	21,500
Camas Creek, Camas to Mud Lake	4,900
Mud Lake	16,400
Beaver Creek, Dubois to Camas	17,500
Little Lost River	47,700
Big Lost River	51,500
Milner Gooding Canal	17,800
Little Wood River, abv Picabo to Richfield	15,900
Little Wood River, nr Richfield to abv Milner Gooding Canal	8,300
Big Wood River, Magic Reservoir to Shoshone Canal	52,700
Big Wood River, abv Thorn Creek to Gooding	-30,100
Big Wood River, Gooding to nr Gooding	-4,700
Total	552,900

PROCEDURE

Calibrated transmissivity and storage coefficient values were used for the base study simulation. The head values of the last (24th) timestep of the calibration period (April 1980 through March 1981) were used as the initial ground water surface. The boundary configuration and grid size were the same as in the calibration (Figure 5).

The base study was developed in two steps. First, using the initial parameters from the calibration, present level net recharge values for the 24 half month timesteps were repeatedly run in sequence until an equilibrium condition was reached. Equilibrium conditions were assumed to have been reached when change in aquifer storage was less than plus or minus 30,000 ac-ft/yr. This simulation required 58 annual cycles. Ground water surface elevations from the last timestep of year 58 were then used to begin a second simulation to complete the base study. The second simulation was run for an additional 100 years using the same 24 half month inputs used for the first 58 years.

RESULTS

Decreased net recharge in 1992 as compared with 1980, resulted in initial decreases in aquifer storage of approximately 450,000 acre-feet each year. The speed at which the aquifer responds to changes is indicated by the slope of the change in annual storage (Figure 6). After 20 years the change in storage is approximately one half of the initial change. This indicates a relatively slow overall aquifer response to changes in recharge. At equilibrium conditions, represented by the 58th year of the initial simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2665 cfs and 5526 cfs, respectively (Figure 7). These discharges represent *average* spring outflows which would occur over time if no changes were made in current levels of development. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

A water budget for the ESPA modeled area at base equilibrium illustrates the relative magnitude of the combined effect of the various components of net recharge (Figure 8). About 5.2 million acre-feet per year are applied to irrigated land from surface sources (before crop evapotranspiration or deep percolation). Tributary valley underflow and leakage from the HFA total about 2.0 million acre-feet. Precipitation and stream and canal losses are 1.6 and 0.9 million acre-feet per year, respectively. Stream and canal losses include the values from Table 3 (733,400 acre-feet) plus about 250,000 acre-feet loss from the hydraulically connected reach of the Snake River from Neeley to Minidoka. On the discharge side of the water budget, evapotranspiration from the entire area of the ESPA, including surface and ground water irrigated areas as well as non-irrigated areas, is about 3.7 million acre-feet. Base condition spring discharge to the river in the Shelley to Neeley and Kimberly to King Hill reaches is approximately 1.9 and 4.0 million acre-feet, respectively.

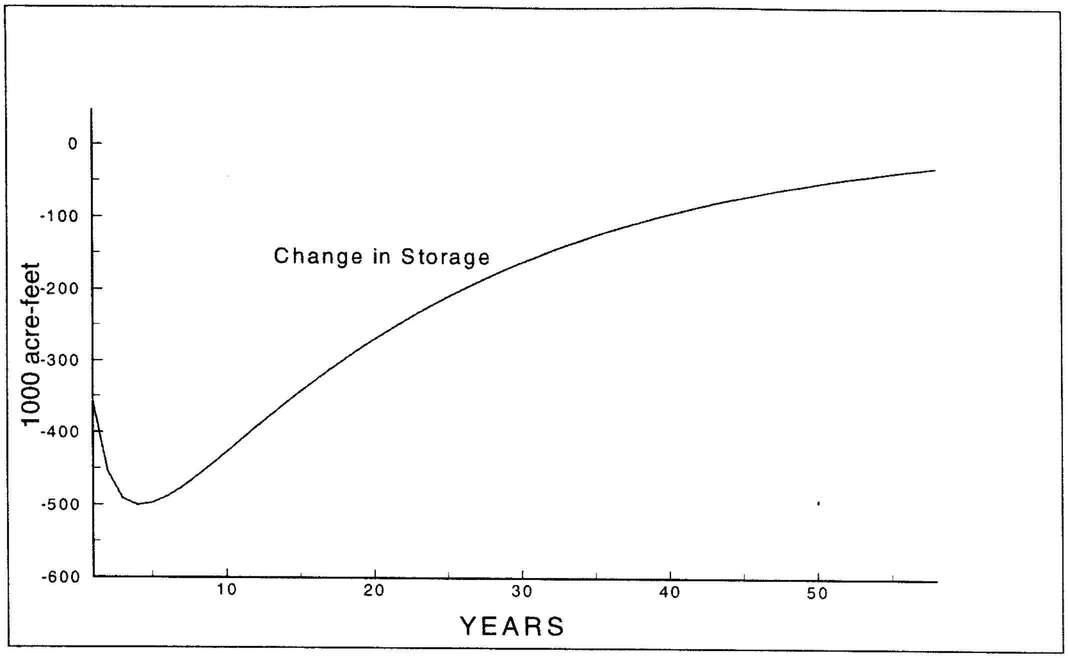


Figure 6. ESPA Change in Aquifer Storage During 58 Years of Present Condition Net Recharge

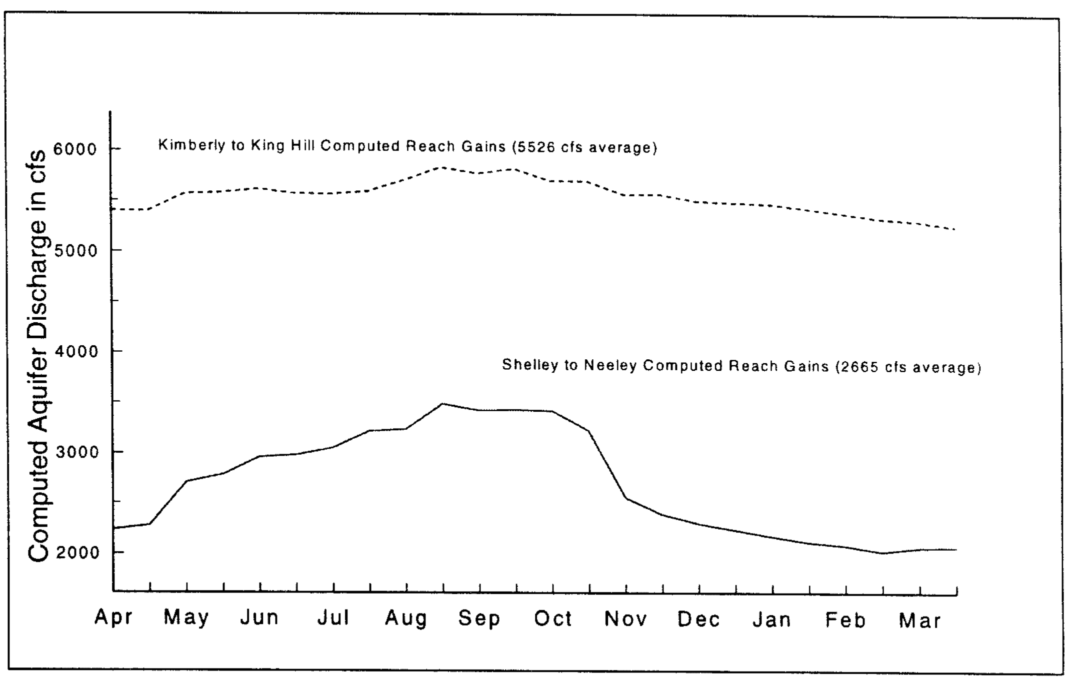


Figure 7. ESPA Aquifer Discharge for Initial Base Simulation year 58

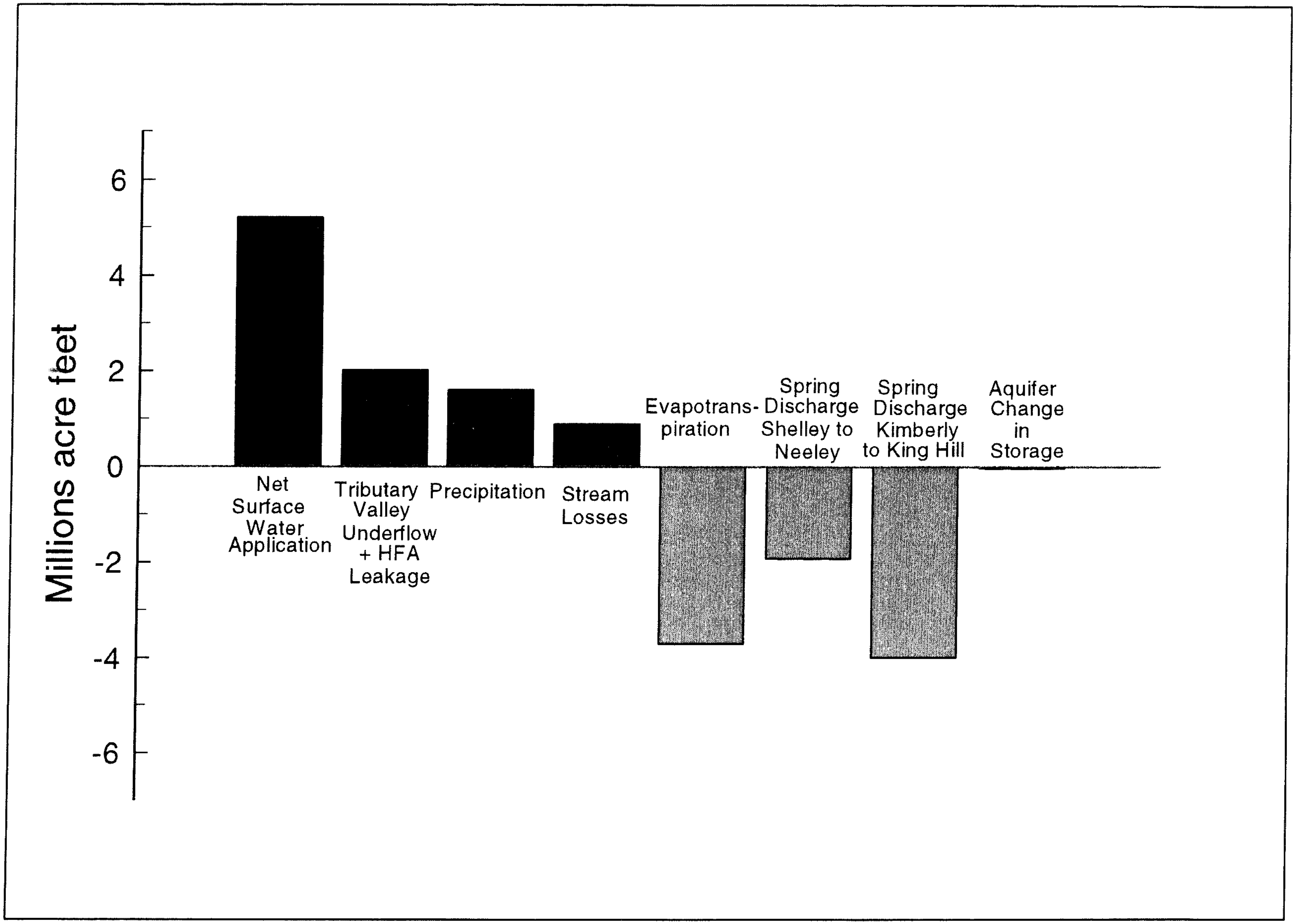


Figure 8. ESPA Modeled Area Water Budget for Base Study

USE OF 100 YEAR BASE STUDY ESPA

The base study is the 100 year simulation beyond the 58th year at which equilibrium occurred using repeated annual cycles of present condition net recharge. Each "what if" study described in the remainder of this report also used the 58th year as a starting point for simulation. However, unlike the base study, net recharge was changed to reflect the condition being studied. The "what if" condition was then run through repeated annual cycles until a new equilibrium was reached (change in aquifer storage less than 30,000 acre-feet per year). The changes in water table elevations and spring discharge for the new condition were then compared to the base study values at the same time and location to assess the impact of the change.

"NO GROUND WATER" STUDY

The "no ground water" study was designed to provide a means of assessing the impact of existing ground water pumping for irrigation on ESPA spring discharges and water table elevations. A model simulation was made after removing the effect of ground water pumping over the modeled area of the ESPA. By comparing the results of this simulation with the base study, an estimate of yearly depletion of spring discharge and reduction in water table elevations from ground water irrigation was made. In general, ground water rights for irrigation are junior to surface water rights in the Upper Snake River basin. The effects of this depletion on senior surface water users in Water District 1 were estimated for an average and a low runoff year as described in the section "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users".

NET RECHARGE

The combined recharge source term for the "no ground water" study is the average net recharge to the ESPA at the present level of development without depletion from ground water irrigation.

Crop and land use data were the same as in the base study with the following exception: depletion due to ground water irrigated area totaling 745,000 acres was removed from net recharge. Ground water irrigated acres in and surrounding the Fort Hall Indian Reservation, 73,000 acres, were left in place under the assumption that water rights for these lands were predominately junior to down-gradient surface water rights. Net evapotranspiration and recharge on irrigated and non-irrigated acres were determined in the same manner as the base study.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the "no ground water" study, as ESPA elevations rise, leakage from the HFA is reduced. A procedure was developed for this study to model HFA leakage in response to changes in head difference using response functions. A routine was added to the ESPA model to calculate this leakage automatically using these response functions. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "no ground water" simulation. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "no ground water" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation which is indicative of the present (1992) effect of ground water depletion. The average date for ground water development in the ESPA was estimated to be 1966 (see "Impacts of ESPA Ground Water Irrigation on Water District 1 Surface Water Users" section).

RESULTS

Increased annual net recharge of approximately 1,358,000 acre-feet due to removing junior ground water depletion as compared to base conditions resulted in initial increases in aquifer storage of more than one million acre-feet each year. The speed at which the aquifer responds to changes is indicated by the slope of the change in annual storage (Figure 9). After 25 years the annual increase in storage was 294,500 acre-feet. At 25 years approximately 70% of the impacts of the change in the recharge have occurred. Equilibrium conditions were not reached until the 100th year when aquifer change in storage was less than 30,000 acre feet per year.

After 25 years of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 3340 cfs and 6030 cfs, respectively (Figure 10). When compared to the base study, the 25 year discharge is an increase of 675 cfs and 500 cfs, respectively (Figure 11). At equilibrium conditions, represented by the 100th year of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 3500 cfs and 6140 cfs, respectively (Figure 12). When compared to the base study, the equilibrium discharge is an increase of 850 cfs and 620 cfs, respectively (Figure 13). These discharges represent estimates of *average* spring discharge and changes in spring discharge that have and will occur due to ground water depletion. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was reduced by approximately 120 cfs after 25 years and 175 cfs after 100 years due to decreased head differences between the regional system and the HFA perched system.

Figure 14 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of no pumping. Increases in ground water levels vary from less than 10 feet at the southern boundaries and western terminus of the aquifer to more than 100 feet in the vicinity of Mud Lake. The majority of the ESPA show increases in water table elevations ranging from 10 to 30 feet.

The large increase in the Mud Lake area water table is likely due to two factors. First, the area is primarily up-gradient from the Mud Lake barrier. The Mud Lake barrier is an area of low transmissivity which magnifies the response of up-gradient water levels to changes in local pumping or recharge as compared to the regional aquifer down gradient. A second cause for the large rise in Mud Lake area water table elevations is that removal of ground water depletion locally (and to a lesser extent, throughout the aquifer) reverses the current trend of declining water table elevations which has been attributed to local overdraft conditions and less underflow from the Egin Bench area.

Results of the "no ground water" study are given in terms of resulting increases in spring discharges and water table elevations after removing ground water pumping. These results are equally valid for the reverse situation to estimate the effect over time that additional ground water pumping has had on the reduction of spring discharge and decline in water table elevations.

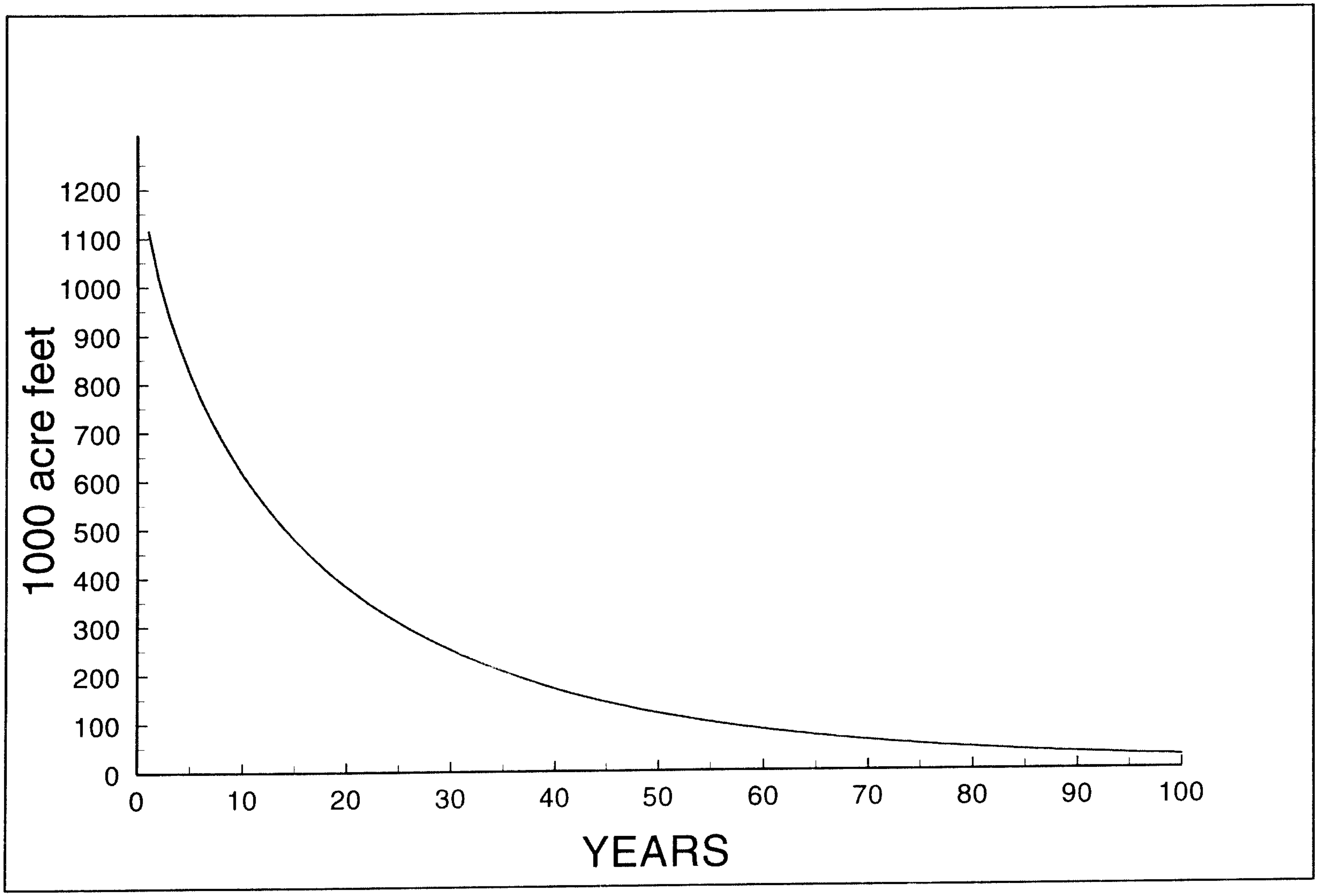


Figure 9. ESPA Change in Aquifer Storage for "No Ground Water" Study

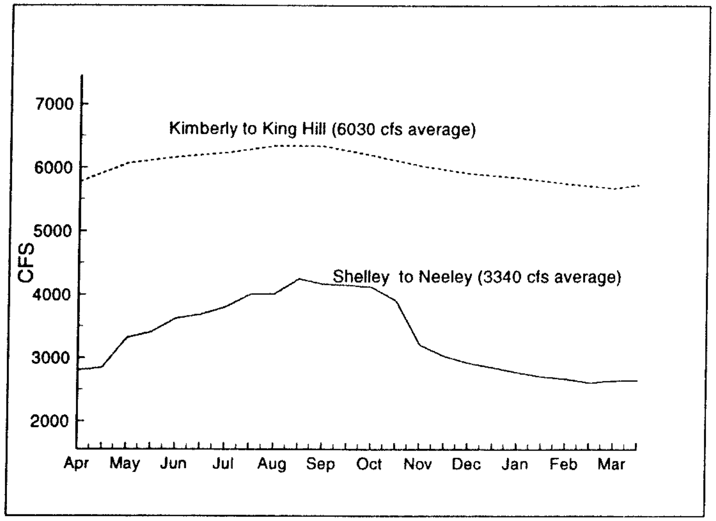


Figure 10. ESPA "No Ground Water" Study - Spring Discharge after 25 Years

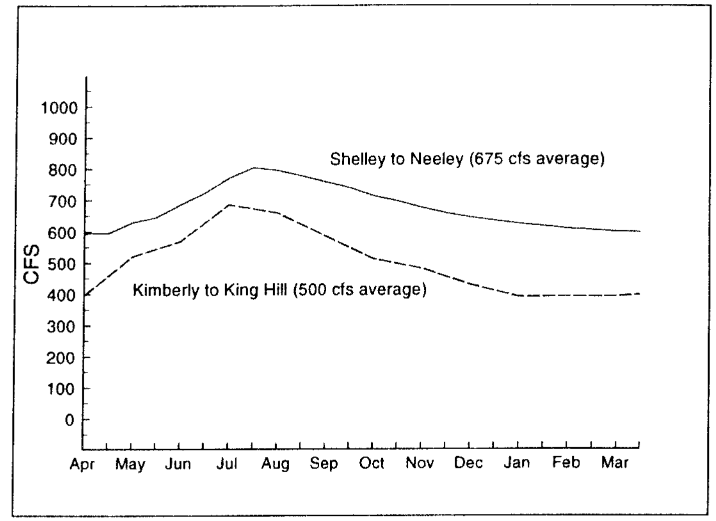


Figure 11. ESPA "No Ground Water" Study - Difference in Spring Discharge from Base after 25 Years

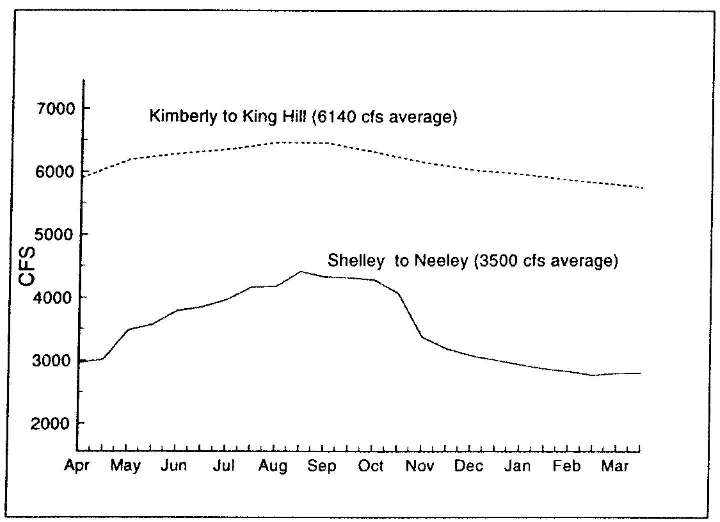


Figure 12. ESPA "No Ground Water" Study - Spring Discharge after 100 years

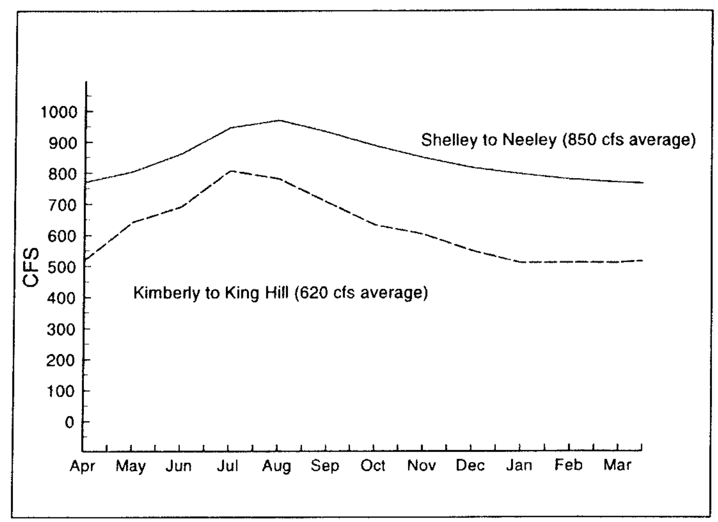
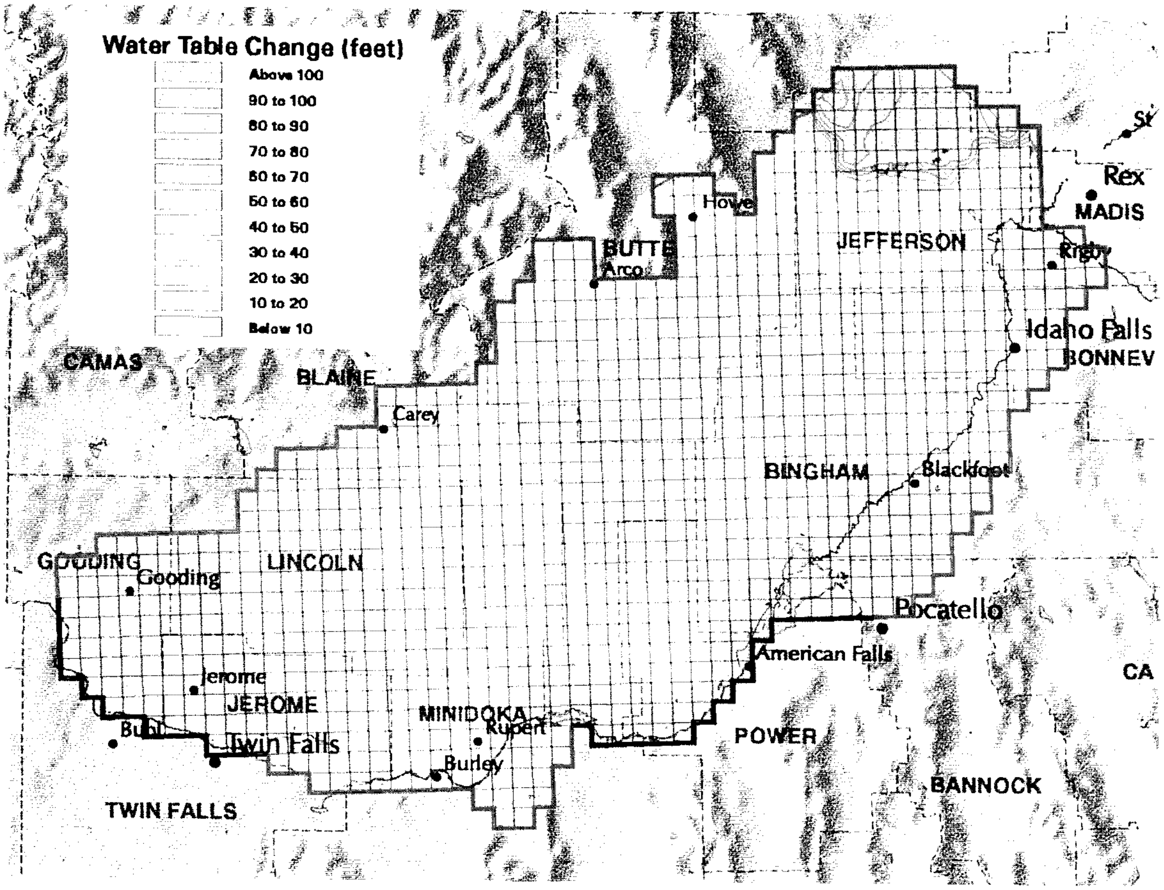


Figure 13. ESPA "No Ground Water" Study - Difference in Spring Discharge from Base after 100 Years

Figure 14. Change in Water Table Elevation After 25 years of No Pumping



☐ 5K Model Cell Size (Hydraulically Connected) (No Flow)

IMPACTS OF ESPA GROUND WATER IRRIGATION ON WATER DISTRICT 1 SURFACE WATER USERS

Irrigation in the Upper Snake River basin was largely confined to surface water sources until the early 1950's. From 1950 to 1992 a steady and dramatic increase in ground water irrigation occurred. By 1992 it was estimated that more than 800,000 acres were irrigated from ground water over the modeled area of the ESPA (see Appendix D). This actually exceeded the 1992 surface water irrigated acres of less than 700,000 acres over the modeled area. Records from the IDWR water rights files indicate that from 1947 through 1992, about 700,000 acres over the ESPA were permitted or licensed for irrigation from a ground water source. The majority of surface water users in Water District 1, the Upper Snake River water regulation district, have rights senior to these ground water rights including the North Side and Twin Falls Canal Companies whose major rights date from 1900 to 1920. Reach gains to the Henrys Fork and Snake River from Shelley to Neeley, which are dependent on conditions on the ESPA, provide a significant portion of natural flow to these and other senior surface water rights. Study elements were included by the technical committee to estimate this effect on natural flow deliveries and to set up a system for use by Water District 1 to account for these effects.

WATER DISTRICT 1 ACCOUNTING

The present accounting system for allocating water has been in use in Water District 1 since 1978 (Sutter, et al, 1983). It resulted from a combination of events following the drought year of 1977 when complaints arose about numerous unmeasured and unregulated diversions. The USGS, which had provided watermaster services for many years, announced it would no longer continue these services when the current watermaster retired. A new method which could handle the complexity of over 300 diversions, as well as more than 650 water rights, was needed. The present computer-based system was developed by IDWR with help from the USBR and Water District 1. The accounting method is conceptually very simple, but becomes complex due to the large number of river reaches, diversions, reservoirs, and water rights. The accounting procedure calculates natural flows, allocates those flows in the order of priority to measured diversions, and then determines stored water used and storage supplies remaining. All computations are made on a daily basis. A more detailed description of the accounting procedure is given in Appendix E.

The method described in this section to assess the impact of junior ground water rights on senior surface rights uses the existing Water District 1 accounting procedure. The "no ground water" simulation estimates the effect of withdrawals on gains to the river. Water distribution accounting offers a means to allocate altered natural flows reflecting those effects to the various river users in accordance with water rights.

PROCEDURE

To estimate the extent of the effects of existing ground water withdrawals on surface water users it was necessary to identify the historic time period over which ground water pumping has occurred to identify a priority date that could be assigned to ground water pumping as a whole. It was considered beyond the scope of this study to assess the effects of pumping with specific priority dates. Ground water rights on file at IDWR for administrative basins 35 and 36 were compiled by year from 1940 through 1992. The cumulative acreage listed for all permits and licenses was calculated yearly for the period. The ratio of accumulated acres to the 1992 total was plotted in Figure 15. This graph illustrates the uniform development of irrigation from ground water; the half way point in this development occurred in approximately 1966. While ESPA ground rights are of varying ages, the average priority of 1966 representing all ground water diversions was chosen to estimate the effects on natural flow distribution in Water District 1. This assumption was considered reasonable since the time period during which any right later than 1940 is met under non-surplus flow conditions is very brief in all years.

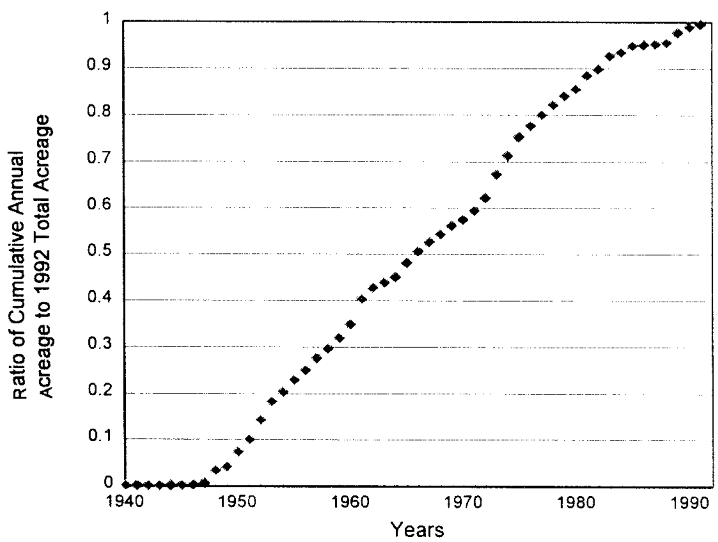


Figure 15. Cumulative Development of Ground Water Irrigation 1940-1992

Results from the "no ground water" study after the 25th year of simulation were selected as input to the Water District 1 accounting. The 25th year values would approximate the average combined effect of ground water pumping on the natural flow in 1992. Two years were chosen as examples for which to rerun the accounting with ground water depletion included. Irrigation year 1993 was chosen to illustrate the effects of an average year when most reservoir storage accounts had filled at the beginning of the irrigation season. Water distribution in 1992, a year of very poor natural flow and carryover reservoir storage in the Snake River system, was chosen to illustrate the effects during a low water year. Runoff in 1993 was approximately 100 percent of average; runoff in 1992 was approximately 50 percent of average.

From the "no ground water" study, it was shown that the gains to two reaches in Water District 1 had been significantly reduced by ground water pumping. These reaches were the lower Henrys Fork and from Shelley to Neeley on the Snake River. By placing diversions in the two affected reaches equal to the estimated reduction in gain with a 1966 water right priority, the accounting can illustrate how the various river rights might have been affected in the test years. Including these "diversions" causes the natural flow to be increased by an equal amount. The allocation process distributes this increased natural flow to the next priority right holder, thus reducing that user's stored water use. When water rights being met are all earlier in priority than the priority date of the ground water rights (1966), older surface rights benefit from greater natural flow, while the ground water diversions are accounted for as using stored water.

In the "no ground water" study, after 25 years of aquifer simulation, losses in the lower Henrys Fork were reduced by an average 121 cfs, or 87,900 acre-feet per year. In the Shelley to Neeley reach, gains to the river increased an average of 673 cfs, or 487,400 acre-feet per year. These two effects were entered into the accounting for Water District 1 as new daily diversions in the two reaches (Tables 4 and 5). Both diversions were assigned a water right priority of January 1, 1967, to represent the 1966 end of year development.

Table 4. Henrys Fork Ground Water Depletion (cfs)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	122	122	122	122	122	120	121	121	121	122	122	122
2	122	122	122	122	122	120	121	121	121	122	122	122
3	122	122	122	122	122	120	121	121	121	122	122	122
4	122	122	122	122	122	120	121	121	121	122	122	122
5	122	122	122	122	122	120	121	121	121	122	122	122
6	122	122	122	122	122	120	121	121	121	122	122	122
7	122	122	122	122	122	120	121	121	121	122	122	122
8	122	122	122	122	122	120	121	121	121	122	122	122
9	122	122	122	122	122	120	121	121	121	122	122	122
10	122	122	122	122	122	120	121	121	121	122	122	122
11	122	122	122	122	122	120	121	121	121	122	122	122
12	122	122	122	122	122	120	121	121	121	122	122	122
13	122	122	122	122	122	120	121	121	121	122	122	122
14	122	122	122	122	122	120	121	121	121	122	122	122
15	122	122	122	122	122	120	121	121	121	122	122	122
16	122	122	122	122	122	121	121	121	122	122	122	122
17	122	122	122	122	122	121	121	121	122	122	122	122
18	122	122	122	122	122	121	121	121	122	122	122	122
19	122	122	122	122	122	121	121	121	122	122	122	122
20	122	122	122	122	122	121	121	121	122	122	122	122
21	122	122	122	122	122	121	121	121	122	122	122	122
22	122	122	122	122	122	121	121	121	122	122	122	122
23	122	122	122	122	122	121	121	121	122	122	122	122
24	122	122	122	122	122	121	121	121	122	122	122	122
25	122	122	122	122	122	121	121	121	122	122	122	122
26	122	122	122	122	122	121	121	121	122	122	122	122
27	122	122	122	122	122	121	121	121	122	122	122	122
28	122	122	122	122	122	121	121	121	122	122	122	122
29	122	122	122	---	122	121	121	121	122	122	122	122
30	122	122	122	---	122	121	121	121	122	122	122	122
31	---	---	122	---	122	---	121	---	122	122	---	122
TOTAL	3662	3663	3791	3422	3788	3617	3753	3639	3767	3780	3658	3781
MEAN	122	122	122	122	122	121	121	121	122	122	122	122
MAX	122	122	122	122	122	121	121	121	122	122	122	122
MIN	122	122	122	122	122	120	121	121	121	122	122	122
AC-FT	7263	7266	7520	6787	7514	7173	7443	7218	7471	7498	7257	7499

IRRIGATION YEAR 1993 TOTAL 44320 MEAN 121 AC-FT 87908

Table 5. Shelley to Neeley Ground Water Depletion (cfs)

DAY	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT
1	676	645	625	608	599	597	629	686	771	804	778	714
2	676	645	625	608	599	594	629	686	771	795	758	714
3	676	645	625	608	599	594	629	686	771	795	758	714
4	676	645	625	608	599	594	629	686	771	795	758	714
5	676	645	625	608	599	594	629	686	771	795	758	714
6	676	645	625	608	599	594	629	686	771	795	758	714
7	676	645	625	608	599	594	629	686	771	795	758	714
8	676	645	625	608	599	594	629	686	771	795	758	714
9	676	645	625	608	599	594	629	686	771	795	758	714
10	676	645	625	608	599	594	629	686	771	795	758	714
11	676	645	625	608	599	594	629	686	771	795	758	714
12	676	645	625	608	599	594	629	686	771	795	758	714
13	676	645	625	608	599	594	629	686	771	795	758	714
14	676	645	625	608	599	594	629	686	771	795	758	714
15	658	634	625	608	599	594	629	686	771	795	758	714
16	658	634	616	604	599	594	629	686	771	795	758	714
17	658	634	616	604	597	594	646	724	804	778	739	696
18	658	634	616	604	597	594	646	724	804	778	739	696
19	658	634	616	604	597	594	646	724	804	778	739	696
20	658	634	616	604	597	594	646	724	804	778	739	696
21	658	634	616	604	597	594	646	724	804	778	739	696
22	658	634	616	604	597	594	646	724	804	778	739	696
23	658	634	616	604	597	594	646	724	804	778	739	696
24	658	634	616	604	597	594	646	724	804	778	739	696
25	658	634	616	604	597	594	646	724	804	778	739	696
26	658	634	616	604	597	594	646	724	804	778	739	696
27	658	634	616	604	597	594	646	724	804	778	739	696
28	658	634	616	604	597	594	646	724	804	778	739	696
29	658	634	616	---	597	594	646	724	804	778	739	696
30	645	634	616	---	597	594	646	724	804	778	739	696
31	---	---	616	---	597	---	646	---	804	778	---	696
TOTAL	19986	19171	19224	16973	18531	17828	19752	21106	24391	24396	22497	21864
MEAN	666	639	620	606	598	594	637	704	787	787	750	705
MAX	676	645	625	608	599	597	646	724	804	804	778	714
MIN	645	634	616	604	597	594	629	686	771	778	739	696
AC-FT	39642	38026	38130	33666	36757	35363	39179	41864	48380	48389	44622	43366

IRRIGATION YEAR 1993 TOTAL 245719 MEAN 673 AC-FT 487384

While maintaining all other hydrologic and water right input data exactly the same as actually occurred in 1993 and 1992, the accounting for both years was rerun for the entire irrigation year, beginning with November 1 through October 31 of the next year. By including the winter months, which are the months when storage reservoirs refill, effects on reservoir fill can also be determined. Reservoir fill is affected by ground water diversions since ground water depletion occurs throughout the entire year, and most reservoir storage rights in Water District 1 are older than 1966 and therefore senior to ground water pumping.

RESULTS

Results of the rerun of 1993 and 1992 water distribution accounting are significant to this study in three areas: a) reservoirs in Water District 1 will accrue more storage as a result of greater natural flow during the period when reservoir rights are being met; b) ground water users will be charged with storage equal to their effect on the natural flow of the river when rights later than 1966 are not being met; and c) surface water users will use less storage water as a result of the greater natural flow supply. The specific reservoir or surface water user affected depends on location, timing, and magnitude of natural runoff.

During the reservoir refill period for 1993 (average runoff year) and 1992 (low runoff year), the total increase in accrued reservoir storage in Water District 1 was 50,000 acre-feet and 215,000 acre-feet, respectively.

The North Side and Twin Falls Canal Companies used approximately 96,000 acre-feet and 160,000 acre-feet less storage water in 1993 and 1992, respectively. Other surface water users used a total of 67,000 acre-feet and 138,500 acre-feet less storage water in 1993 and 1992, respectively. All surface water users used a total of 163,000 acre-feet and 298,500 acre-feet less storage water in 1993 and 1992, respectively (Table 6).

Ground water users were charged with 216,000 acre-feet and 558,000 acre-feet of water that would have been available to senior water rights in 1993 and 1992, respectively.

It is important to note that the accounting simulations for 1993 and 1992 did not involve any change in actual water present in the river system, nor did it involve a change in physical operation. Diversions were substantially below normal rates of usage in 1992, and those same rates were used in the simulation. The study shows, within the context of actual diversions, how allocating the natural flow would have affected credited storage fill and charged storage use. If any changes in the accounting process were to be implemented, such as were assumed in this study, it is likely that patterns and magnitudes of use would change to adjust to actual conditions.

Table 6. Estimated Reduction in Stored Water Used by Surface Irrigators in Water District 1 with Ground Water Pumping Depletion Added to Natural Flow (acre-feet)

User	1993	1992
North Side Canal Company	43,000	50,000
Twin Falls Canal Company	53,000	110,000
Reservoir District #2	0	17,500
Minidoka and Burley Irr. Districts	43,000	41,000
All others	24,000	80,000
TOTAL	163,000	298,500

EFFECTS OF INCREASES IN SURFACE WATER IRRIGATION EFFICIENCY

Irrigation from surface water sources now constitutes over half the total recharge to the ESPA. As irrigated agriculture developed over the ESPA this recharge rapidly displaced flow from tributary valleys as the primary aquifer recharge. Surface diversions peaked in the 1970's and dropped dramatically in the drought year of 1977 (Figure 16). Even though subsequent water years included many which were above average runoff, diversions did not return to the pre-1977 level. Diversions overlying the aquifer averaged almost 600,000 acre-feet less in the ten years following 1977 as compared to the ten year period prior to 1977. As shown by Figure 16, the four year moving average of total diversions continued to decline into the 1990's. Small, but noticeable, drops in diversions from the Big and Little Wood Rivers have also occurred in recent years.

Conversion from gravity methods to the more efficient sprinkler irrigation was undoubtedly the principal reason that diversion rates remained down, but better water management at the farm, canal, and water district levels also occurred as a result of the drought. Another factor was the 1976 Teton Dam failure which caused many irrigators to replace their destroyed gravity systems with sprinklers.

In addition to ground water pumping, increase in surface irrigation efficiency, which appears to be permanent, is the other major change causing ESPA water levels and outflows to decline. This section describes the process of estimating the effect of surface diversion reductions on the aquifer. It is also likely that the trend of increasing surface diversion efficiency will continue. This section also examines the effect of further declines in surface diversions.

"1965-1976 SURFACE WATER DIVERSIONS " STUDY

The average diversion in the twelve year period prior to 1977, 1965-76, was chosen to represent the peak of surface water irrigation. Base study diversions (1982-1992 average) were replaced by the average during that period. A one hundred year simulation of the aquifer was run to determine the response of the aquifer to this change.

NET RECHARGE

The combined recharge source term for the "1965-1976 surface water diversions" is the average net recharge to the ESPA at the present level of development with increased recharge from surface water irrigation that had occurred in the 1965-1976 time period.

Crop and land use data were the same as in the base study. Acreage irrigated by surface and ground water sources were kept at 1992 conditions (Appendix C). Net evapotranspiration and recharge on irrigated and non-irrigated acres were determined as in the base study with the exception that surface irrigation diversions to each service area were determined by averaging the 1965 through 1976 measurements reported in the Water District 1 watermaster annual report (Water District 1, 1965-1976). The average annual total of the 1965-1976 diversions overlying the ESPA was approximately 7,780,000 acre-feet as compared to the base study 1982-1992 average annual total of 6,970,000 acre-feet. The net increase in recharge to the aquifer was approximately 810,000 acre feet per year.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

Leakage from the HFA was calculated from response functions added to the ESPA model. As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the "1965-1976 surface water diversions" study, as ESPA elevations rise due to increased recharge, leakage from the HFA is reduced. A procedure was developed for this study in which HFA leakage was varied in response to changes in head difference. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "1965-1976 surface water diversions" simulation. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "1965-1976 surface water diversions" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation.

RESULTS

Increased annual net recharge of approximately 810,000 acre-feet due to increasing recharge from surface diversions as compared to base conditions resulted in initial increases in aquifer storage of more than 400,000 acre-feet each year. The speed at which the aquifer responds to these changes is indicated by the slope of the change in annual storage (Figure 17). After 25 years the annual increase in storage was approximately 100,000 acre-feet. At 25 years approximately 75% of the impacts of the change in the recharge have occurred. Equilibrium conditions were not reached until the 100th year when aquifer change in storage was approximately 30,000 acre feet per year.

After 25 years of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2950 cfs and 5900 cfs, respectively (Figure 18). When compared to the base study, the 25 year discharge is an increase of 287 cfs and 371 cfs, respectively (Figure 19). At equilibrium conditions, represented by the 100th year of simulation, aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged 2980 cfs and 5950 cfs, respectively (Figure 20). When compared to the base study, the equilibrium discharge is an increase of 327 cfs and 423 cfs, respectively (Figure 21). These discharges represent estimates of *average* spring discharge and differences in spring discharge that would have occurred if diversions had not declined. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was reduced by approximately 48 cfs after 25 years and 62 cfs after 100 years due to decreased head differences between the regional system and the HFA perched system.

Figure 22 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of increased diversions. Increases in ground water levels vary from less than 10 feet throughout the central portion of the aquifer to more than 40 feet southeast of Burley.

Results of the "1965-1976 surface water diversions" study are given in terms of increases in spring discharges and water table elevations. These results are equally valid in estimating the effect as a reduction over time that more efficient irrigation practices has had on the reduction of spring discharge and the decline in water table elevations.

"FUTURE IRRIGATION EFFICIENCY" STUDIES

To estimate the potential impact of further reductions in surface water diversions over the ESPA, a series of additional reductions in present levels of surface water diversions were included in the net recharge to the aquifer. Base study diversions (1982-1992 average) were replaced by the appropriate lesser values. Model simulations of the aquifer were run to determine the response of the aquifer to these changes.

NET RECHARGE

The combined recharge source terms for the "future irrigation efficiency" studies are the average net recharge to the ESPA at the present level of development with decreased recharge from surface water irrigation that would occur with a 5, 10, 15 and 20 percent reduction in diversions.

Crop and land use data were the same as in the base study. Acreage irrigated by surface and ground water sources were kept at 1992 conditions (Appendix C). Net evapotranspiration and recharge on the irrigated and non-irrigated acres were determined as in the base study with the exception that surface irrigation diversions to each service area were determined by reducing the base study net diversions (1982-1992 averages) by 5, 10, 15 and 20 percent. The average annual total of the base study diversions overlying the ESPA was approximately 6,970,000 acre-feet. Net diversions were computed by deducting surface return flows of approximately 1,770,000 from total diversions. The decrease in net recharge to the aquifer after accounting for surface return flows was approximately 260,000, 520,000, 781,000, and 1,041,000 acre feet per year for the 5, 10, 15 and 20 percent reductions, respectively.

Tributary valley underflow, tributary direct surface runoff, and river and canal reach gains (losses) were computed as in the base study.

Leakage from the HFA was calculated from response functions added to the ESPA model. As water table elevations in the ESPA underlying the HFA change, the head dependent leakage from the HFA also varies. In the case of the "future irrigation efficiency" study, as ESPA elevations fall due to the decreased recharge, leakage from the HFA is induced. A procedure was developed for this study in which HFA leakage was varied in response to changes in head difference. A discussion of the interaction between the ESPA and HFA is contained in Appendix D as well as a description of the development of the response functions.

PROCEDURE

Calibrated transmissivity values and storage coefficient values were used for the "future irrigation efficiency" simulations. Head values identical to the beginning timestep of the base study were used as the initial ground water surface (see "ESPA Base Study" section). The boundary configuration and grid size were the same as in the calibration (Figure 5). Using the initial parameters from the calibration, "future irrigation efficiency" net recharge values for the 24 half month timesteps were repeatedly run in sequence until equilibrium was reached for each of the four studies. Results were compared to the base study at equilibrium conditions and after the 25th year of simulation.

RESULTS

Decreased annual net recharge ranging from 260,000 to 1,041,000 acre-feet due to decreasing recharge from surface diversions as compared to base conditions resulted in initial decreases in aquifer storage throughout the study simulations. Equilibrium conditions for each of the studies were reached by the 100th year when aquifer change in storage was less than 30,000 acre feet per year.

After 25 years of simulation with reduced diversions of 5, 10, 15, and 20 percent, reductions in aquifer discharge from the base study in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged from 142 cfs to 565 cfs and from 132 cfs to 527 cfs, respectively (Figures 23 and 24). At equilibrium conditions, represented by the 100th year of simulation, reduction in aquifer discharge in the Shelley to Neeley reach and the Kimberly to King Hill reach averaged from 158 cfs and 629 cfs and 152 cfs and 607 cfs, respectively (Figures 25 and 26). These discharges represent estimates of *average* spring discharge and differences in spring discharge that would have occurred if surface water irrigators become more efficient. Seasonal variations are depicted by the results, but year to year variations are not since net recharge was based on long term averages.

Leakage from the HFA into the regional system was induced by amounts ranging from 22 to 87 cfs after 25 years and from 25 to 99 cfs after 100 years due to decreases in diversions of 5, 10, 15 and 20 percent, respectively as a result of head differences increases between the regional system and the HFA perched system.

Figure 27 shows the change (from the base study) in simulated April ground water levels for the ESPA after 25 years of a 15 percent decrease in surface water diversions. Decreases in ground water levels vary from less than 4 feet throughout the central portion of the aquifer to more than 40 feet southeast of Burley.

The estimated annual change from base study in the Shelley to Neeley and Kimberly to King Hill simulated aquifer discharge and the difference in gain to the Henrys Fork due to change in HFA leakage for all irrigation efficiency studies in this section are summarized in Table 7 for the 25th and 100th year of simulation.

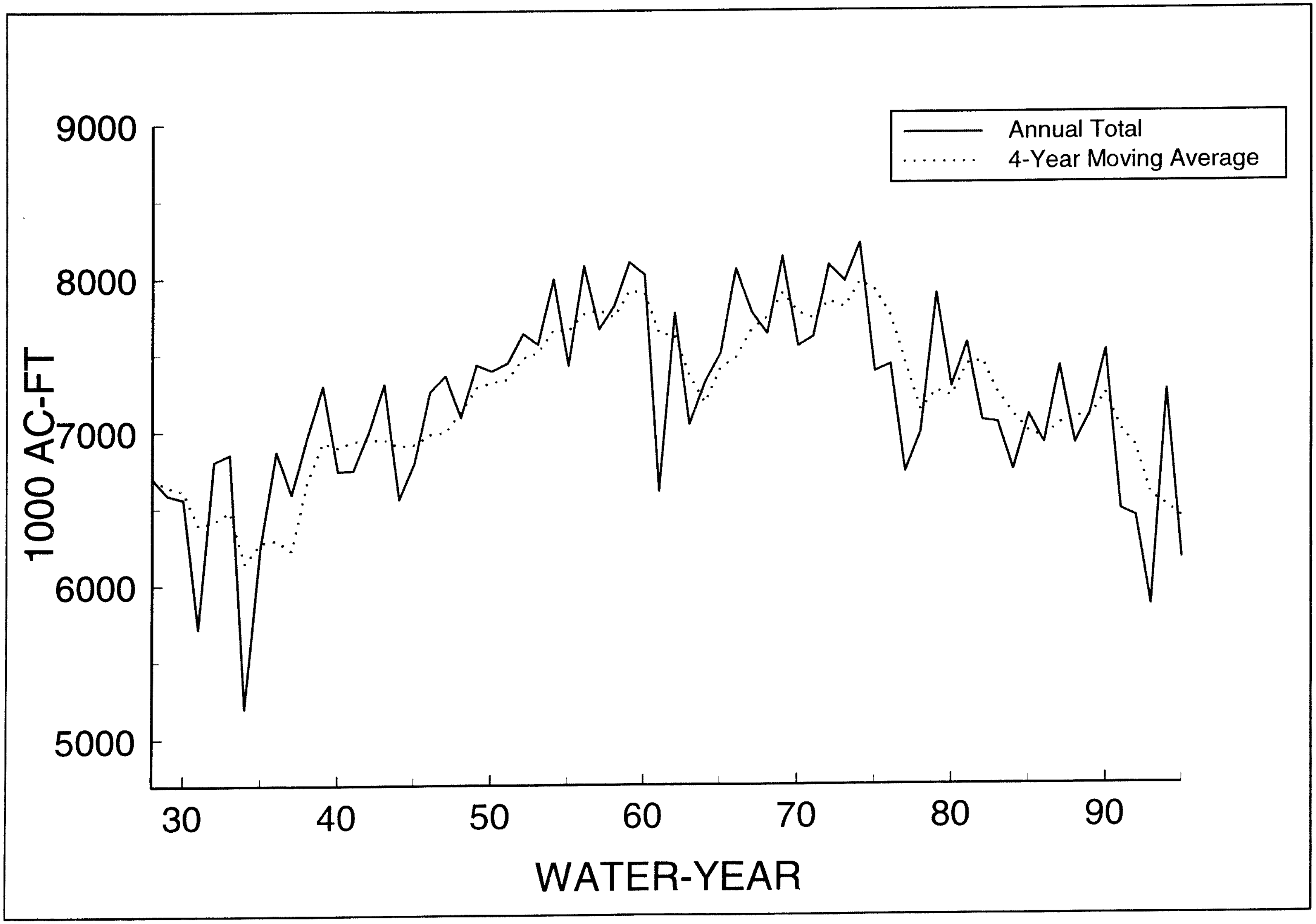


Figure 16. Sum of Historic Diversion from Surface Water Overlying the ESPA

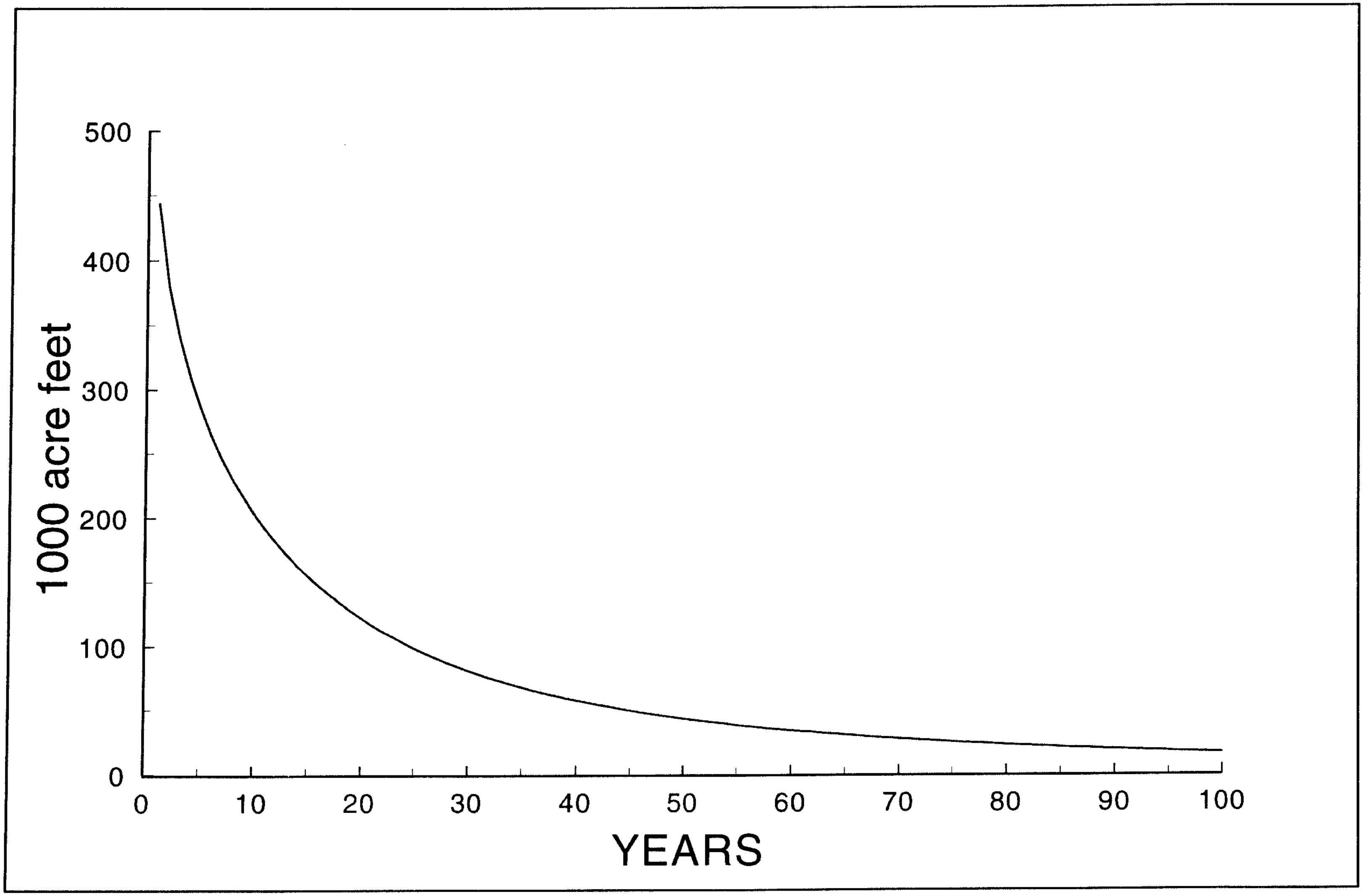


Figure 17. ESPA Change in Aquifer Storage for "1965-1966 Surface Water Diversions" Study

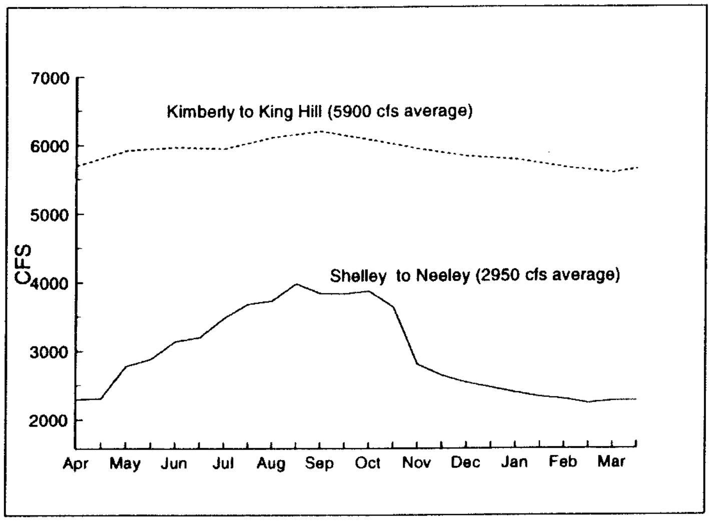


Figure 18. ESPA "1965-1976 Surface Water Diversion" Study - Spring Discharge after 25 Years

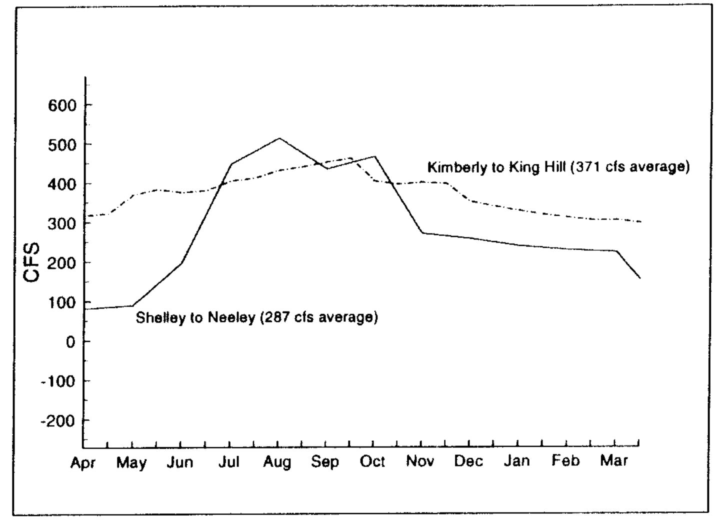


Figure 19. ESPA "1965-1976 Surface Water Diversion" Study - Difference in Spring Discharge after 25 Years

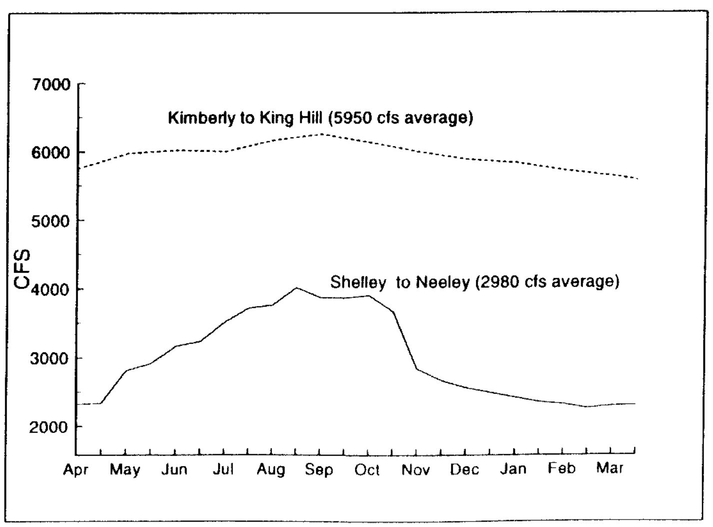


Figure 20. ESPA "1965-1976 Surface Water Diversion" Study Spring Discharge after 100 Years

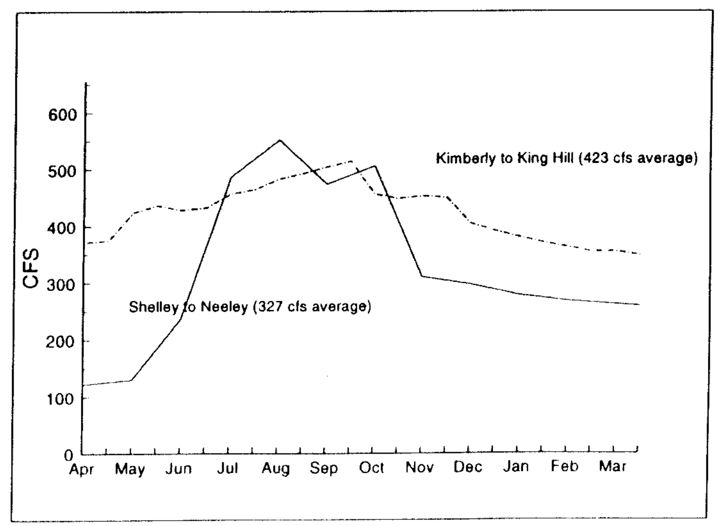
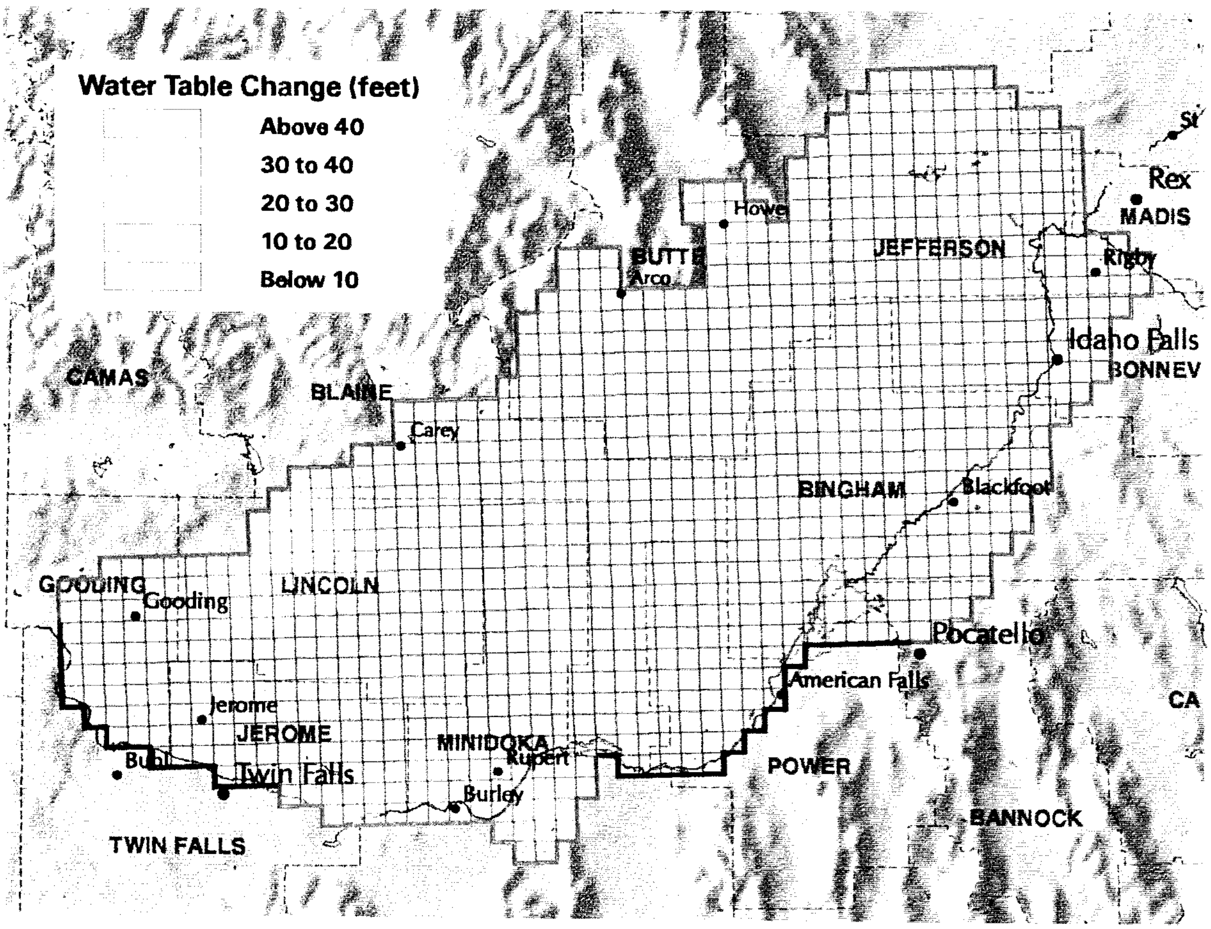


Figure 21. ESPA "1965-1976 Surface Water Diversion" Study- Difference in Spring Discharge from Base after 100 Years

Figure 22. Change in Water Table Elevation after 25 years Assuming Diversion Efficiencies from 1965 - 1976



5K Model Cell Size (Hydraulically Connected) (No Flow)

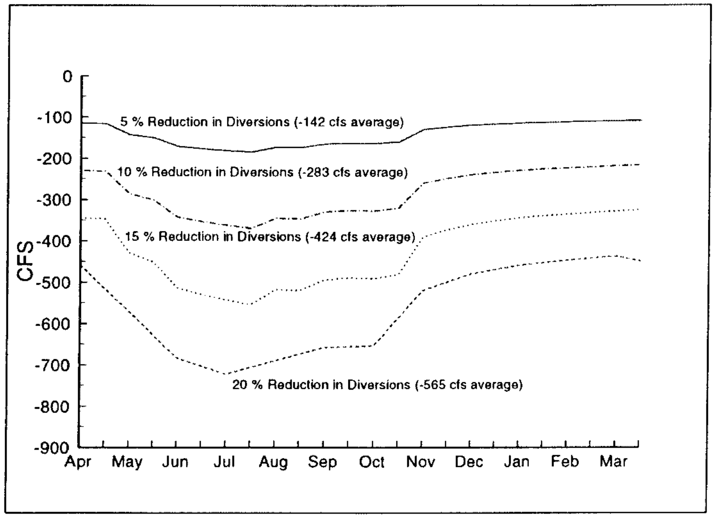


Figure 23. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Shelley to Neeley Reach from Base after 25 Years

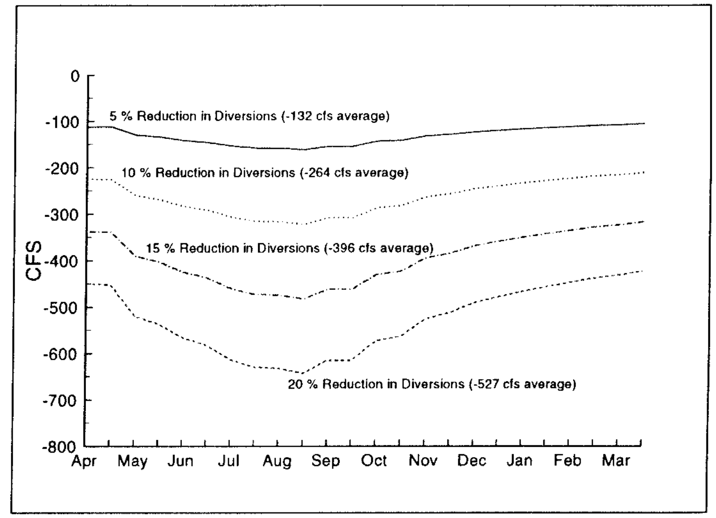


Figure 24. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Kimberly to King Hill Reach from Base after 25 Years

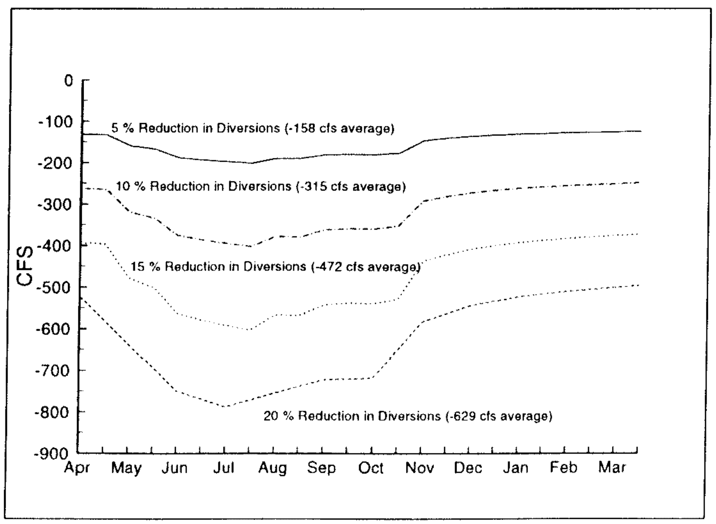


Figure 25. ESPA "Future Irrigation Efficiency" Study - Difference in Spring Discharge for Shelley to Neeley Reach from Base after 25 Years

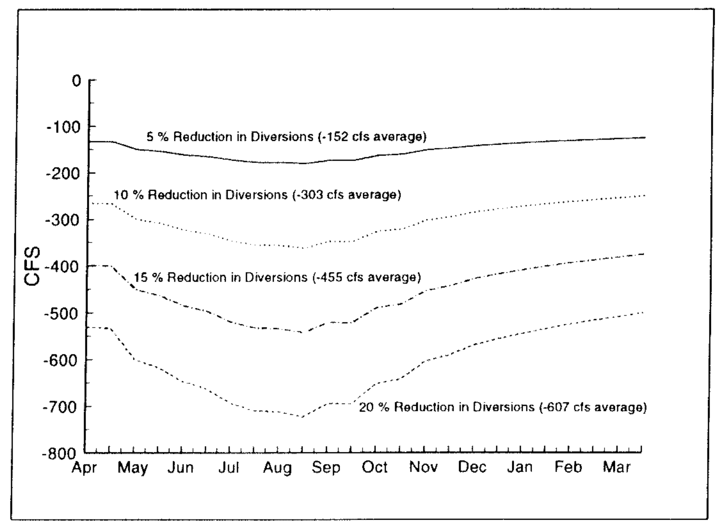


Figure 26. ESPA "Future Irrigation Efficiency " Study - Difference in Spring Discharge for Kimberly to King Hill Reach from Base after 100 Years

Figure 27. Change in Water Table Elevation after 25 years Assuming a 15 Percent Reduction in Diversion from Base Study

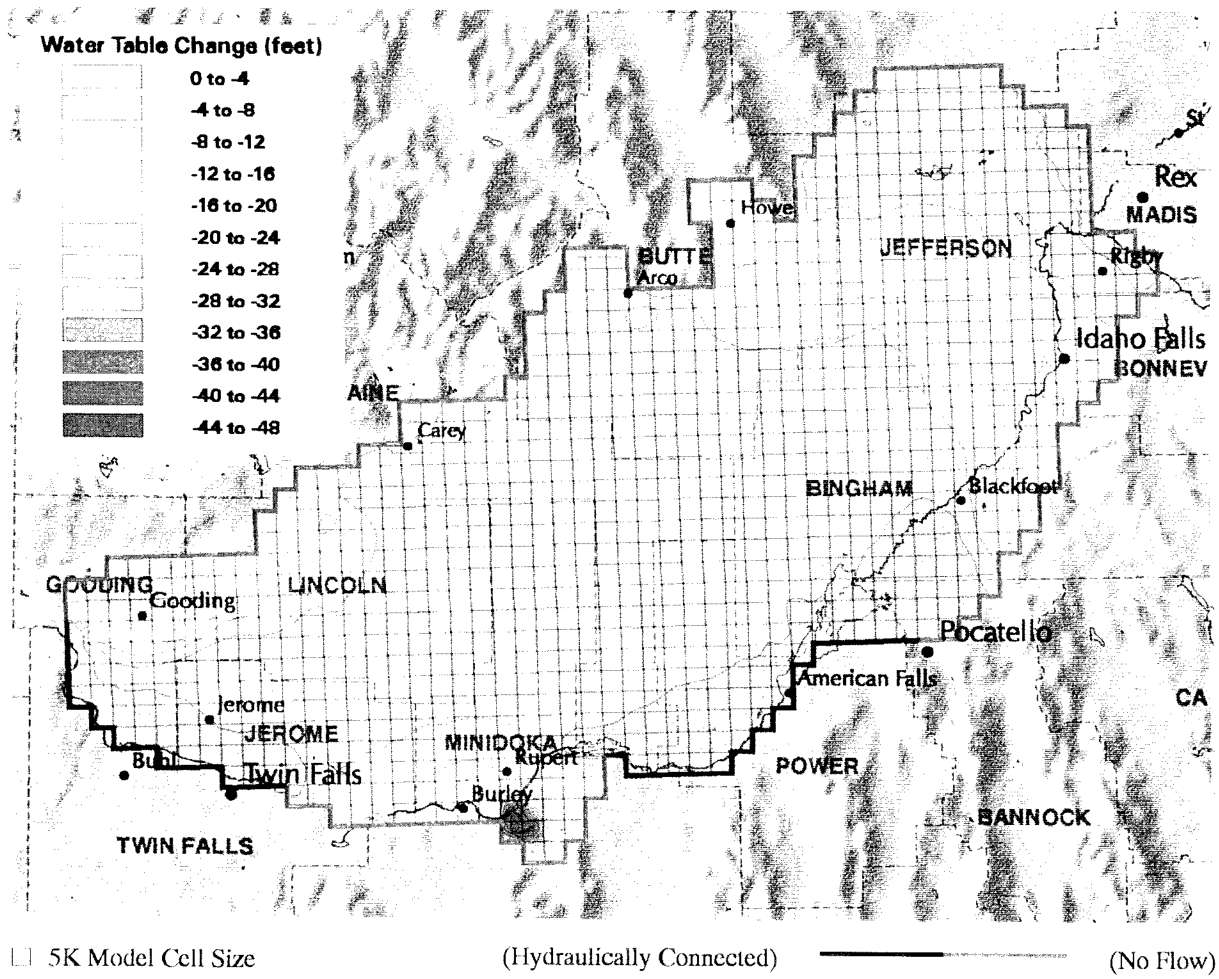


Table 7. Summary of Effects on ESPA for Irrigation Efficiency Studies

Study	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)	Difference in Computed Discharge from Base Study Shelley to Neeley (cfs)	Difference in Computed Discharge from Base Study Kimberly to King Hill (cfs)	Difference in gain to Henrys Fork from Base Study due to Change in HFA Leakage (cfs)
	After 25th Year of Simulation			After 100th Year of Simulation		
1965-76 Surface Diversions	287	371	48	327	423	62
5% Reduction Surface Diversions	-142	-132	-22	-158	-152	-25
10% Reduction Surface Diversions	-283	-264	-44	-315	-303	-50
15% Reduction Surface Diversions	-424	-396	-64	-472	-455	-75
20% Reduction Surface Diversions	-565	-527	-87	-629	-607	-99